NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

INDOOR PROPAGATION SIMULATION SOFTWARE

by

Juan Carlos Calle

September 2000

Thesis Advisor: Jovan Lebaric

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13. ABSTRACT (maximum 200 words)

Computer simulation can be used to predict the signal strength in complex indoor environments. Signal propagation prediction is essential for determining the coverage of WLAN's (Wireless Local Area Networks). Increasing use of WLANs within infrastructures that have been built prior to the installation of the wireless networks requires measurements, semi-empirical models, or computer simulations to determine the number and location of access points for optimum coverage. In cases where the infrastructure has yet to be built (as in a new class of ships) the simulation may be the only option for WLAN coverage prediction. In such a case, blueprints may be used in conjunction with the indoor propagation simulation software in order to predict the best places to install the access points. The indoor propagation simulation software differs from the outdoor propagation software used for the cellular networks because of the differences in the characteristics of indoor and outdoor propagation channels.

This thesis explains the characteristics and structure of a Wireless Local Area Network and presents the computer simulation results the 2.4 GHz wireless signal propagation inside an enclosed space. A building at the Naval Postgraduate School, where some previous physical measurements have been conducted, was selected for the indoor propagation simulation.

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INDOOR PROPAGATION SIMULATION SOFTWARE

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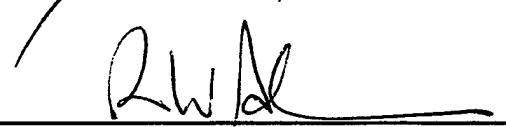
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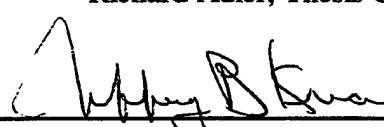
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This thesis explains the characteristics and structure of a Wireless Local Area Network and presents the computer simulation results the 2.4 GHz wireless signal propagation inside an enclosed space. A building at the Naval Postgraduate School, where some previous physical measurements have been conducted, was selected for the indoor propagation simulation.

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ACKNOWLEDGMENT

I must take this opportunity to acknowledge the constant support of my wife, Patricia, who I had the luck to marry while I was attending NPS. I also want to recognize my parents, Carlos and Esperanza, for all the sacrifices they made in order for me to get an education which, led me to Monterey.

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I. INTRODUCTION

Installing a wireless network system in a building is challenging with respect to the exact number and the best placement of the base stations. The placement is done either empirically or based upon measurements, resulting in considerable uncertainty regarding the minimum required number of base stations and the achievable coverage.

In this thesis, accurate predictions of indoor signal propagation for a Wireless Local Area Network with the IEEE 802.11 standard are considered, using propagation simulation software, in order to determine the best place and proper number of access points to be installed for a particular environment.

A.   PURPOSE

This research is based on the US Navy's interest to place Wireless Local Area Networks (WLANs) inside future ships and submarines. Since these future ships will have more electronic equipment but limited personnel assets, it will be important to increase the productivity of every crewmember onboard. If we are able to give each crewmember appropriate information with minimal delay, the increase in efficiency will be considerable.

B.   OBJECTIVES

The objective of this thesis is to evaluate software that can be used to determine the best place to install an access point (transmitter/receiver) inside an enclosed space. Since we are interested in the next-generation ships, we must take into account that the infrastructure where the network will be installed has not been built yet. Consequently,

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we will use the blueprints of a building located at the Naval Postgraduate School for the software evaluation, especially since there are results from another thesis where physical measurements of a WLAN were taken and documented. These measured results can be used for comparison with the simulation predictions.

C. THESIS OUTLINE

This thesis consists of five chapters. Chapter I presents the introduction. Chapter II provides background information about the Indoor Wireless Channel and the LAN's IEEE 802.11 standard. Chapter III examines the different indoor propagation simulation software that are available. Chapter IV examines the simulation results using the software called PlaceBase. Chapter V concludes the thesis and provides recommendations.

II. BACKGROUND

A. THE MOBILE INDOOR PROPAGATION CHANNEL

1. Wireless Characteristics

Most of the early research on the topic of indoor propagation channel dates back to 1959 [1] and most of this work focused on tunnels and mines. After the success of the cellular mobile radio systems, more measurement and modeling efforts started to appear. However, the models for outdoor cellular systems are not appropriate for indoor applications because of the difference in the channel characteristics. Although there is currently an intense effort to develop semi-empirical models for indoor (and indoor to outdoor and vice versa) propagation, that may lead to efficient tools for indoor propagation prediction (in a statistical sense), there is also a need for an accurate indoor simulation tool for accurate predictions in particular environments to which the "general" statistical models may not be applicable (such as shipboard compartments).

Accounting for the different state of progress in the wireless and wired worlds, we can identify the following major challenges faced by the wireless communication system designer:

- **Fading:** Wireless channels are time varying. The range of channel operating characteristics for wireless modems is much wider than for typical wired

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channels. The nonstationary nature of the channel has a large impact on spectrally efficient transmitter-receiver design as well as channel capacity. Achieving low-bit-error-rate data transmission is particularly challenging in rapidly varying channels subject to a high Doppler Spread.

- **Multi-User:** The wireless users are spatially separated (with a significant variation of mutual distances) and often uncoordinated. Spectral efficiency in multipoint-to-point and point-to-multipoint communication is significantly more challenging than in single-user communication, particularly when data rate requirements are heterogeneous. Although the rudiments of multi-user communication theory date back to the early 1970s, academic research in this area did not start until the 1980s, and mostly as a reaction to the wireless revolution.

- **Power Limitation:** Since the majority of wireless terminals are battery operated, power efficiency, in addition to spectral efficiency, is crucial. This applies not only to transmitted power but also to circuit-dissipated power. As computational complexity translates into dissipated power, sophisticated designs required to approach capacity may not be advisable in a battery-operated terminal. Fortunately, the advances in low-power-dissipation sub-micron complementary metal oxide semiconductor (CMOS) circuit design

make increasingly complex designs not only feasible but also preferable from the standpoint of power efficiency.

2. Multipath

Interference caused by signals bouncing off of walls and other barriers and arriving at the receiver at different times is called multipath interference. Multipath interference affects Infrared (IR), Radio frequency (RF), and Microwave (MW) systems. Frequency Hopping Spread Spectrum (FHSS) inherently solves the multipath problem by "hopping" between a large number of frequencies. Similarly, Direct Sequence Spread Spectrum (DSSS) systems use large bandwidths for signal transmissions thus minimizing the probability of deep signal fading due to multipath. Other systems use specific anti-multipath algorithms to reduce the signal fading effects.

Figure 1 shows the effect of Non-Line of Sight (there is no direct signal from the transmitter) multipath fading, where we can see that all energy is scattered from scatterers located around the wireless terminal. This causes either signal cancellation or enhancement, with deep and often rapid variations in signal amplitude.

Figure 2 shows the multipath effect when there is a Line of Sight transmission, adding a strong coherent component to the random scattered components. The signal fading is less pronounced than in the NLoS case and we have a distinct direction of arrival.

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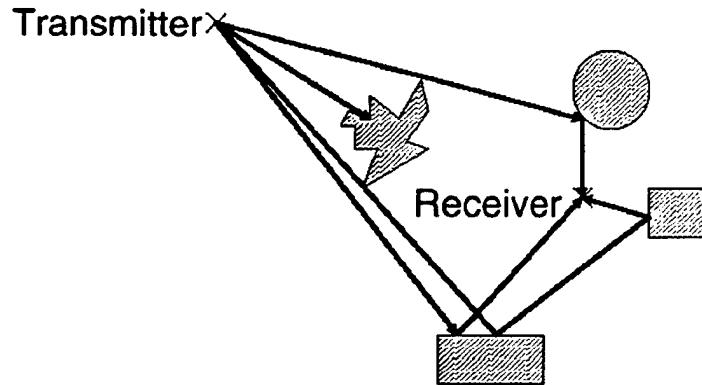
Figure 1. Example of Multipath Fading *Non-Line of Sight* Case (From Ref [2])
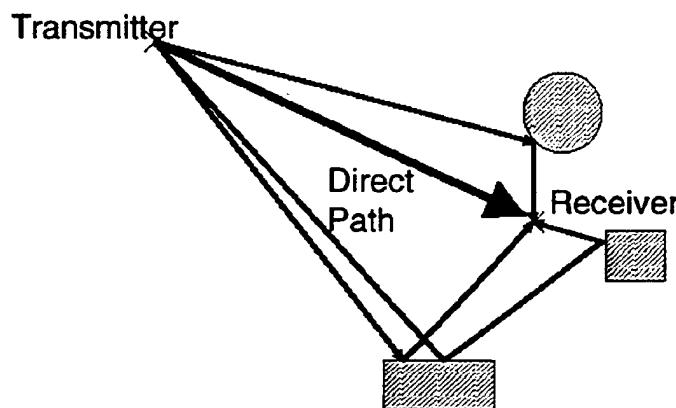

Figure 2. Example of Multipath Fading *line of sight* Case (From Ref [2])

B.   WIRELESS LAN

A wireless local area network (LAN) is a flexible data communications system implemented as an extension to, or as an alternative for, a wired LAN. Using radio frequency (RF) technology, wireless LANs transmit and receive data over the air,

minimizing the need for wired connections. Thus, wireless LANs combine data connectivity with user mobility.

Wireless LANs have gained popularity in the commercial markets, including the health-care, manufacturing, warehousing, and academia. These have profited from the productivity gains of using hand-held terminals and notebook computers to transmit real-time information to centralized hosts for processing. The military is also beginning to exploit the different advantages of wireless LANs. Today wireless LANs are becoming more widely recognized as a general-purpose connectivity alternative for a broad range of purposes.

1. Why Does the Navy Need Wireless Networks on Ships?

The widespread reliance on networking and the rapid growth of the Internet and online services are strong testimonies to the benefits of shared data and shared resources. With wireless LANs, crewmembers can access shared information without looking for a place to plug in, and network managers can set up or augment networks without installing or moving wires. Wireless LANs offer the following productivity, convenience, and cost advantages over traditional wired networks:

- **Mobility**: Wireless LAN systems can provide LAN users with access to real-time information from anywhere on the ship. This mobility supports productivity and service opportunities not possible with wired networks.

- **Installation Speed and Simplicity**: Installing a wireless LAN system can be fast and easy and can eliminate the need to pull cable through compartments and bulkheads.

- **Installation Flexibility**: Wireless allows the network to go where wire cannot go.

- **Reduced Cost**: While the initial investment required for wireless LAN hardware can be higher than the cost of wired LAN hardware, overall installation expenses and life-cycle costs can be significantly lower. Long-term cost benefits are greatest in dynamic environments requiring frequent moves and changes.

- **Scalability**: Wireless LAN systems can be configured in a variety of topologies to meet the needs of specific applications and different type of ships. Configurations are easily changed and range from peer-to-peer networks suitable for a small number of users to full infrastructure networks of thousands of users. This enables roaming over a broad area.

2. Wireless LAN Technology

Manufacturers of wireless LANs have a range of technologies, with its own set of advantages and limitations, to choose from when developing a wireless LAN solution.

a. *Narrowband Technology*

A narrowband radio system transmits and receives user information on a specific radio frequency. Narrowband radio keeps the radio signal frequency range as narrow as possible, with just enough bandwidth to accommodate the required information rate. Undesirable cross talk between communications channels is avoided by carefully coordinating different users on different channel frequencies. In a radio system, privacy and noninterference are maintained by the use of separate radio frequencies. The receivers filter out all signals except the ones on their designated frequencies. One drawback of narrowband technology is that the end-user must obtain a FCC license for each site where it is employed.

b. *Spread Spectrum Technology*

Most wireless LAN systems use spread-spectrum technology, a wideband radio frequency technique developed by the military for use in reliable, secure, mission-critical communications systems. Spread-spectrum is designed to trade off bandwidth efficiency for reliability, integrity, and security. In other words, more bandwidth is consumed than in the case of narrowband transmission, but the tradeoff produces a signal that is, in effect, louder and thus easier to detect, provided that the receiver knows the parameters of the spread-spectrum signal being broadcast.

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If a receiver is not tuned to the right frequency, a spread-spectrum signal looks like background noise. There are two types of spread spectrum radio: frequency hopping and direct sequence.

- **Frequency Hopping Spread Spectrum Technology**

A frequency-hopping spread-spectrum (FHSS) uses a carrier that changes frequency in a pattern known to both transmitter and receiver. When the terminals are properly synchronized, the message is maintained a single channel. To an unintended receiver, FHSS appears to be short-duration impulse noise [9].

- **Direct Sequence Spread Spectrum Technology**

Direct-sequence spread-spectrum (DSSS) generates a redundant bit pattern for each information bit to be transmitted. This bit pattern is called a chip or chipping code. The longer the chip, the greater the probability that the original data can be recovered (at the expense of wider bandwidth). Even if one or more bits in the chip are lost or changed during transmission, statistical techniques embedded in the radio can recover the original data without the need for retransmission. To an unintended receiver, DSSS appears as low-power wideband noise and is rejected (ignored) by most narrowband receivers [9].

c.   *Infrared Technology*

A third technology, little used in commercial wireless LANs, is infrared.   IR systems use very high frequencies, just below visible light in the

electromagnetic spectrum, to carry data. Like light, IR cannot penetrate opaque objects; it is either direct (line-of-sight) or diffuse technology. Inexpensive direct systems provide very limited range (3 feet) and typically are used for personal area. High performance directed IR is impractical for mobile users and is therefore used only to implement fixed sub-networks. Diffuse (or reflective) IR wireless LAN systems do not require line-of-sight, but cells are limited to individual rooms.

3. Wireless LAN Operation

Wireless LANs use electromagnetic waves of radio or infrared wavelengths to communicate information from one point to another without relying on any physical connection. EM waves are often referred to as carriers because they simply perform the function of delivering information in the form of modulation of the EM energy to a remote receiver. The data being transmitted is superimposed on a carrier for extraction at the receiving end. Once data is superimposed or modulated onto the carrier, the signal occupies more than a single frequency, since the frequency or bit rate of the modulating information modifies the carrier.

Multiple carriers can exist in the same space at the same time without interfering with each other if the waves are transmitted on different carrier radio frequencies. To extract data, a receiver is tuned to only one frequency while rejecting all other frequencies.

In a typical wireless LAN configuration, an *access point* (AP), containing a transmitter/receiver as shown in Fig. 3, connects to a wired network from a fixed location, using standard cabling. The access point always receives, buffers, and transmits data

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between the wireless LAN and the wired network infrastructure. A single access point can also support a small group of users and usually functions within a range of less than one hundred feet but can operate up to several hundred feet. The access point (or the antenna attached to the access point) is usually mounted at a high location for maximum coverage but may be mounted essentially anywhere that is practical as long as the desired coverage is obtained.
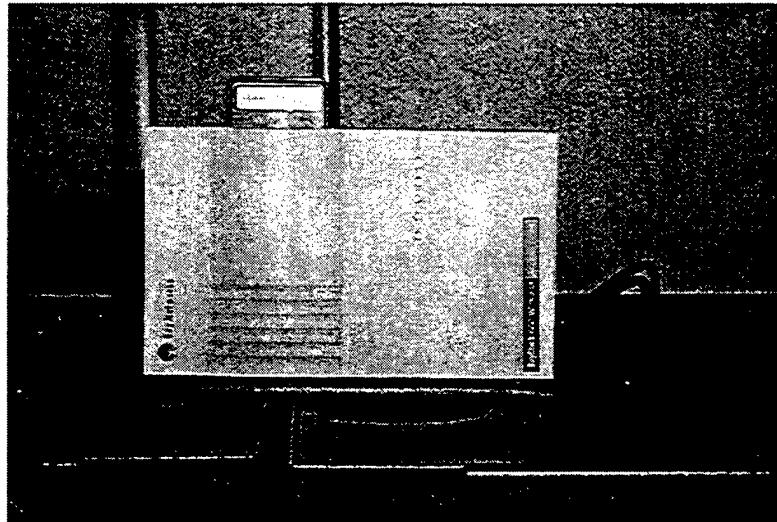

Figure 3. Access Point Installed at the Network Lab of the NPS ECE Department.

End users access the wireless LAN through wireless-LAN adapters, which are constructed on PC cards in notebook or palmtop computers, as PCI cards in desktop computers, or integrated within hand-held computers as shown in Fig. 4. Wireless LAN

adapters provide an interface between the client Network Operating System (NOS) and the antenna. The nature of the wireless connection is transparent to the NOS.
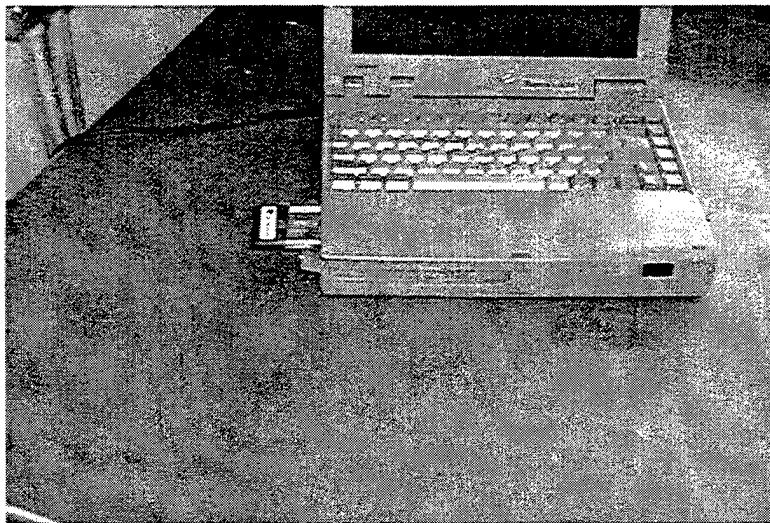
Figure 4. WLAN PC Card in a Notebook Computer.

4. Wireless LAN Configurations

Wireless LANs can be either simple or complex. At its most basic, two PCs equipped with wireless adapter cards can function as an independent network when they are within communication range of one another. This is called a peer-to-peer network, and is shown in Fig. 5. These on-demand networks, require no administration or preconfiguration. In this case, each client would have access only to the resources of the other client and not to a central server.

Figure 5. A Wireless Peer-to-Peer Network (from Ref.[7])

Installing an access point can extend the range of an ad-hoc network, effectively doubling the range at which the devices can communicate. Since the access point is connected to the wired network, each client would have access to server resources as well as to other clients. An example of this is shown in Fig. 6. Each access point can accommodate many clients; the specific number depends on the number and nature of the transmissions involved. Many real-world applications exist where a single access point services from 15 to 50 client devices.
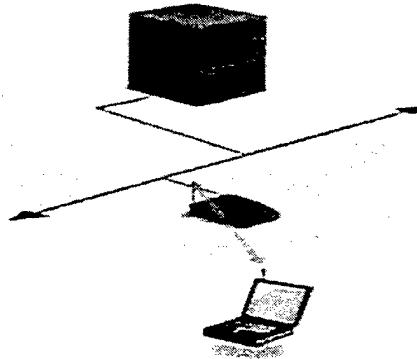

Figure 6. Client and Access Point (from Ref. [7])

Access points have a finite range, on the order of 500 feet indoors and 1,000 feet outdoors. On large Navy vessels such as Frigates, or Submarines, installing more than one

access point will probably be necessary. Access point positioning is accomplished by means of a site survey (physical measurements), or in the case of this thesis, by having a tool that will predict the signal strength at various locations via simulation. The goal is to blanket the coverage area with overlapping coverage "cells" such that clients might range throughout the area without ever losing network contact. More than one access point topology is shown in Fig. 7. The ability of the users to move seamlessly among a cluster of access points is called *roaming*. Access points handoff clients from one to another in a manner that is invisible to the client, while ensuring unbroken connectivity.
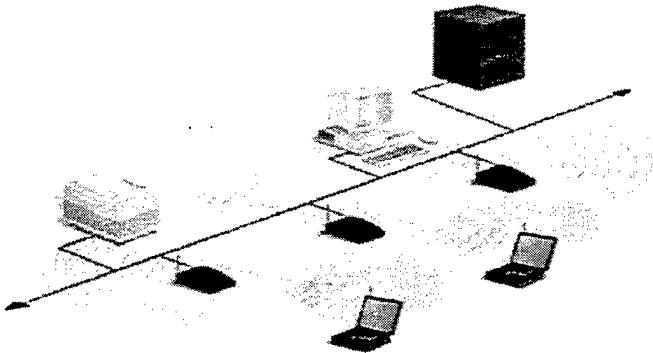
Figure 7. Multiple Access Points and Roaming (from Ref. [7])

To solve particular problems of topology, the network designer might choose to use Extension Points (EP) to augment the network of Access Points (AP). Extension Points look and function like access points, but they are not tethered to the wired network, as are APs. EPs function as their name implies: they extend the range of the network by relaying signals from a client to an AP or another EP. EPs may be strung

together in order to pass along messaging from an AP to far-flung clients, similar to the action of humans in a bucket brigade, passing pails of water, hand-to-hand from a water source to a fire. In Fig. 8 the WLAN with an extension point is shown and in Fig. 9 is an extension point that is being tested in the ECE network lab.
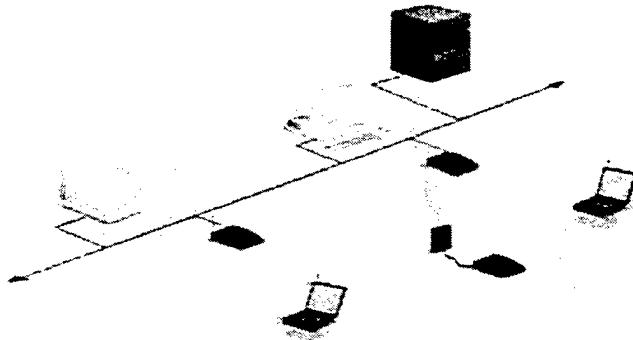
Figure 8. Use of an Extension Point, (from Ref. [7])
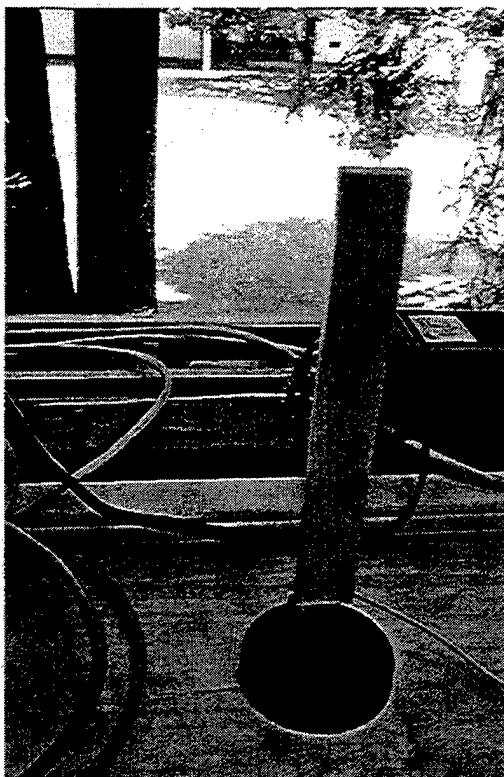
Figure 9. Extension Point from the NPS ECE Network Lab.

The last item of wireless LAN equipment to consider is the directional antenna. Assume a wireless LAN in building A is to be extended to include a "leased" building B, one mile away. One solution is to install a directional antenna on each building, each antenna targeting the other. An example of this arrangement is shown in Fig. 10. The antenna on A is connected to the wired network via an access point. The antenna on B is similarly connected to an access point in building B, extending wireless LAN connectivity in that facility.
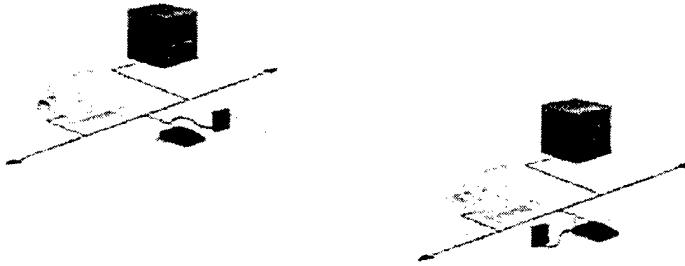
Figure 10. The Use of Directional Antennas (from Ref [7])

5. Technological and Implementation Issues

- **Range and Coverage:** The distance over which RF and IR communication can be established is a function of transmitter power, receiver performance and the propagation path, especially in indoor environments. Interactions with typical building objects, including walls, metal, and even people, can affect how the electromagnetic energy propagates, directly affecting the range and coverage of a particular system. Solid objects block infrared signals, imposing additional limitations on IR systems. Most wireless LAN systems use RF because radio waves can partially penetrate most indoor walls and obstacles. The range (or radius of coverage) for typical wireless LAN systems varies from under 100 feet to more than 300 feet. Coverage can be extended, and true freedom of mobility via roaming can be provided through microcells or micronets.

- **Throughput:** Actual throughput performance in wireless LANs is equipment and installation dependent, just as it is in wired LANs. Factors that affect throughput include the number of users, propagation factors such as range and multipath, and the type of wireless LAN system used. Latency and bottlenecks on the wired portions of the LAN also affect throughput. Data rates for the most common commercial wireless LANs are in the 1.6 Mbps range. Users of traditional Ethernet or Token Ring LANs generally experience little difference in performance when using a wireless LAN. Wireless LANs provide throughput sufficient for the most common LAN-based office applications, including electronic mail exchange, access to shared peripherals, Internet access, and access to multi-user databases and applications. By comparison, state-of-the-art V.90 modems transmit and receive at optimal data rates of 56.6 Kbps. In terms of throughput, a wireless LAN operating at 1.6 Mbps is almost thirty times faster.

- **Integrity and Reliability:** Wireless data technologies have been proven through more than fifty years of wireless application in both commercial and military systems. While radio interference can cause degradation in throughput, such interference is rare in the workplace. Robust designs of proven wireless LAN technology and the limited distance over which signals travel can produce connections that are far more robust than cellular phone connections and provide data integrity performance equal to or better than wired networking.

- **Compatibility with Existing Networks:** Most wireless LANs provide *military standard* interconnections with wired networks, such as Ethernet or Token Ring. Wireless LAN nodes are supported by network operating systems in the same fashion as any other LAN node: through the use of the appropriate drivers. Once installed, the network treats wireless nodes like any other network component.

- **Interoperability of Wireless Devices:** Wireless LAN systems from different vendors might not be interoperable, for several reasons. First, different technologies do not interoperate. A system based on *spread spectrum frequency hopping* (FHSS) technology is not compatible with another system based on *spread spectrum direct sequence* (DSSS) technology. Second, systems using different frequency bands will not interoperate even if they both employ the same technology. Third, systems from different vendors may not interoperate even if they both employ the same technology and frequency band, due to differences in implementation by each vendor.

- **Interference and Coexistence:** The unlicensed nature of radio-based wireless LANs make them susceptible to some measure of interference . Microwave ovens are a potential concern, but most wireless LAN designers have accounted for microwave interference. Another possible concern is the co-location of multiple wireless LANs. While wireless LANs from some manufacturers interfere with

other wireless LANs, others coexist without interference. Careful selection must be made by evaluating each vendor's specific system.

- **Licensing Issues:** In the United States, the Federal Communications Commission (FCC) regulates most radio transmissions, including those used by wireless LANs. Other nations have corresponding regulatory agencies. Wireless LANs are typically designed to operate in portions of the radio spectrum where the FCC does not require licensing. In the U.S. most wireless LANs broadcast over one of the ISM (Instrumentation, Scientific, and Medical) bands. These include 902-928 MHz, 2.4-2.483 GHz, 5.15-5.35 GHz, and 5.725-5.875 GHz. For wireless LANs to be sold in a particular country, the manufacturer of the wireless LAN must ensure its certification by the appropriate agency in that country.

- **Simplicity and Ease of Use:** The wireless nature of a WLAN is transparent to a user's NOS, and applications work the same as they do on wired LANs. Wireless LAN products incorporate a variety of diagnostic tools associated with the wireless elements of the system; however, products are designed so that most users rarely need these tools. Wireless LANs simplify many of the installation and configuration issues that plague network managers. Since access points are the only portion of wireless LANs that require cabling, cable pulling is minimized. This simplifies moves, adds, and changes simpler for WLANs. Finally, the portable nature of wirelesses LANs lets network managers preconfigure and

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troubleshoot the software aspects of entire networks before installing them at remote locations. Once configured, wireless LANs can be moved from place to place with little or no modification.

- **Security**: Because wireless technology has roots in military applications, security has long been a design criterion for wireless devices. Security provisions are typically built into wireless LANs, making them more secure than most wired LANs. It is extremely difficult for unintended receivers (eavesdroppers) to listen in on wireless LAN traffic. Complex encryption techniques make it impossible for all but the most sophisticated to gain unauthorized access to network traffic. In general, individual nodes must be security-enabled before they are allowed to participate in network traffic.

- **Radiation Safety:** The output power of wireless LAN systems is very low and is, much less than that of a hand-held cellular phone. Since radio waves attenuate rapidly with distance, personnel in the area of a wireless LAN system are exposed to very little RF energy.

III. INDOOR PROPAGATION SOFTWARE

A. SOFTWARE TOOLS FOR DESIGNING AND PREDICTING PERFORMANCE OF INDOOR WIRELESS SYSTEMS

This thesis research was initiated with a search for software that would meet the following requirement:

A propagation prediction software that would aid in designing indoor WLANs. There are several types of such software, and the following examines some of them.

1. WiSE (Lucent Technologies)

WiSE is a system for designing indoor wireless systems. Given building data (wall locations and composition), WLAN system parameters, and desired AP locations, WiSE determines system performance (e.g., received power and delay spread) throughout the building or at specific points. For the WLAN specified and the required signal strength threshold, WiSE determines base-station locations which will maximize the fraction of the building over which the performance requirement is met. A sophisticated graphical user interface allows interactive design and optimization. A sample output screen is shown in Fig. 11.
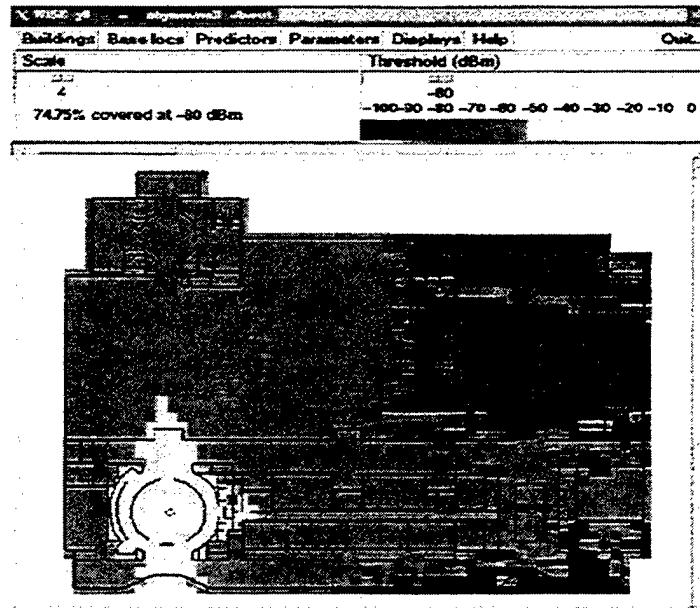
Figure 11. WiSE Output Screen (from Ref. [3])

2. CINDOOR (University of Cantabria, Spain)

CINDOOR is a software engineering tool for use in the design, planning, and effective implementation of wireless systems in enclosed spaces. CINDOOR features a flexible propagation prediction process , which allows the analysis of indoor and outdoor environments and the interaction between them. The numerical modeling method is based on a full three-dimensional implementation of the Geometric Optics/Unified Theory of Diffraction (GO/UTD). Ray tracing is efficiently carried out by combining Image Theory with Binary Space Partitioning algorithms. The space-time distribution of the electromagnetic field is processed to obtain a set of WLAN performance parameters: Coverage (mean power), fading statistics, power delay profile, and other associated parameters, such as rms delay spread and coherence bandwidth are produced. A typical Cindoor output screen is shown in Fig. 12.

The legend reads (top to bottom):
[0, -6] dB
[-6, -12] dB
[-12, -18] dB
[-18, -24] dB
[-24, -30] dB
[-30, -36] dB
[-36, -42] dB
[-42, -48] dB
[-48, -54] dB
[-54, -60] dB
[-60, -66] dB
[-66, -72] dB
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[-78, -84] dB
[-84, -90] dB
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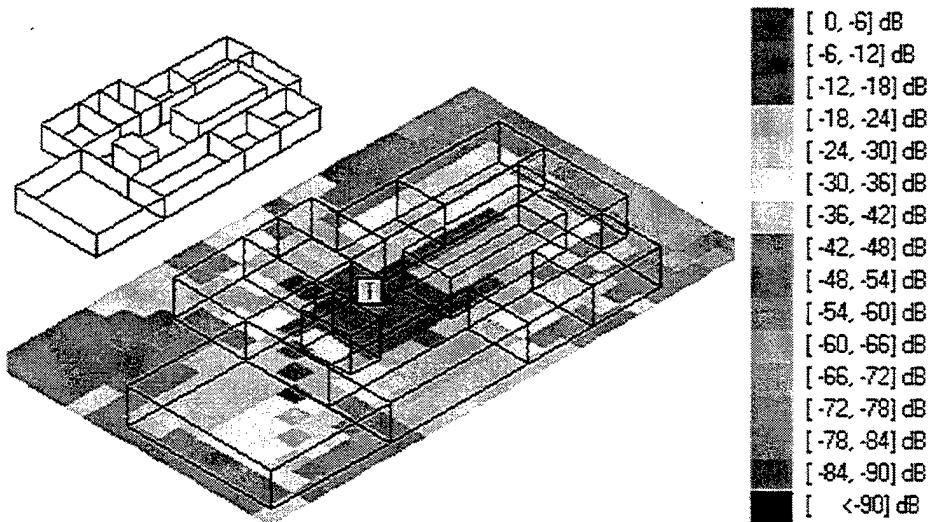
Figure 12. Cindoor Output Screen (from Ref. [4])

3. WinProp (AWE)

WinProp's unique Combined Network Planning(CNP) features are ideal for use in macro, micro and picocell network planning. It features terrain (macrocell) predictions using the parabolic equation method, predictions for urban cells, indoor receivers with penetration of buildings in mobile communication networks , indoor wireless networks, and planning of wireless LAN's (WLAN). Some output products of WinProp include prediction of field strength, received power, prediction of both delay spread and fast fading. A sample output screen from Winpro is shown in Fig. 13.

25
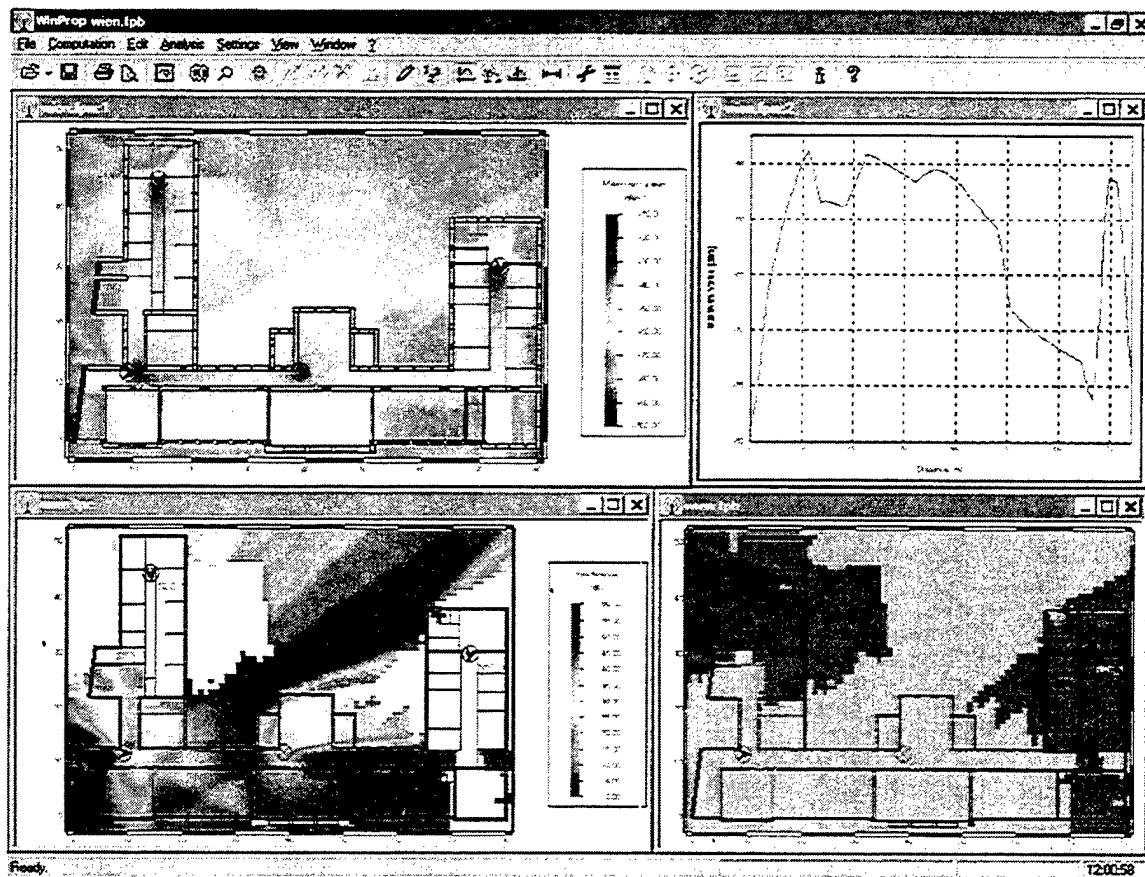
Figure 13. Winpro Output Screen (From Ref. [5])

4. SitePlanner (Wireless Valley Communications)

SitePlanner is a fully-integrated design, measurement, optimization, and management engineering tool for in-building, campus-wide, and microcell wireless communications systems. The tool suite includes the Predictor, InFielder, and Optimatic modules that work together for all phases of deployment, maintenance, and optimization of a local wireless system. One of the output screens of the Predictor, module from SitePlanner, is shown in Fig. 14.
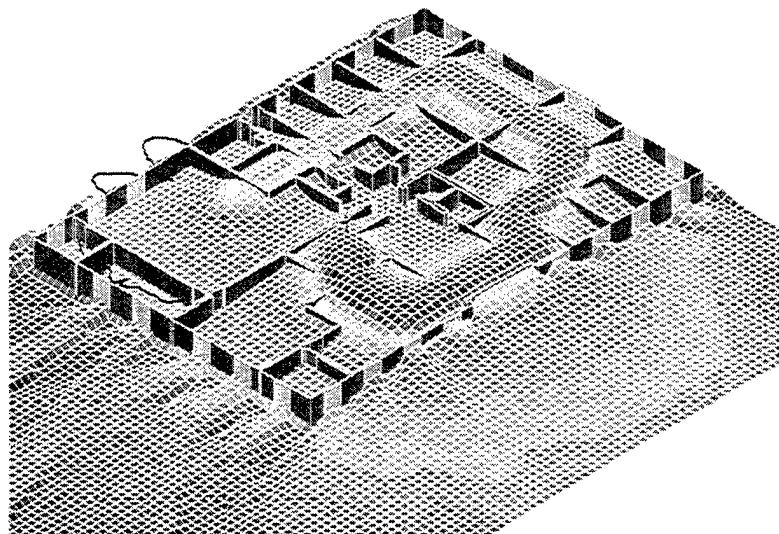
Figure 14. Predictor Coverage Map Output Screen (From Ref. [6])

5. PlaceBase

PlaceBase was designed for two- and three-dimensional modeling of radio propagation in buildings, in the frequency range from 500 to 5200MHz. PlaceBase uses Geometric Optics and the Multi-Channel Coupling (MCC) algorithm, which reduces the computation load while providing reasonable prediction accuracy. PlaceBase considers the pattern and orientation of transmitter antennas and calculates multiple reflections and transmissions produced by structural elements of the building.

Placebase was chosen for the simulation in this thesis. The process to select it was the following:

We started testing a Demo version for Cindoor, the problems with this software was, that it was not user friendly, it was difficult to build the model and it did not have a printed output. Then we tested a Demo version of WinProp, the problem with this demo was that it did not allow us to build different types of indoor models. After this we tried to

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test Site Planner but the company that produces this software does not provide Demo versions. There was a visit from one of their representatives but we were not able to test the software with our own model or frequency parameters. Finally we were able to get a Demo version of Placebase. This software was the one that gave us the flexibility to build our own model and that is why Placebase was chosen.

IV. SIMULATION

A.   PHYSICAL MEASUREMENTS

As stated before, indoor signal strength measurements in the 2.4GHz ISM band are documented in another thesis [8]. The measurements were made in Bullard Hall on the campus of the Naval Postgraduate School, using a wireless PCMCI card (IEEE 802.11 standard) and its accompanying software. The software presents Signal to Noise Ratio (SNR) on the computer screen while the user moves around the enclosed space, as shown in Fig. 15. Both signal and noise are shown on a linear scale from 0 to 100. Note that the drawing is not to scale.
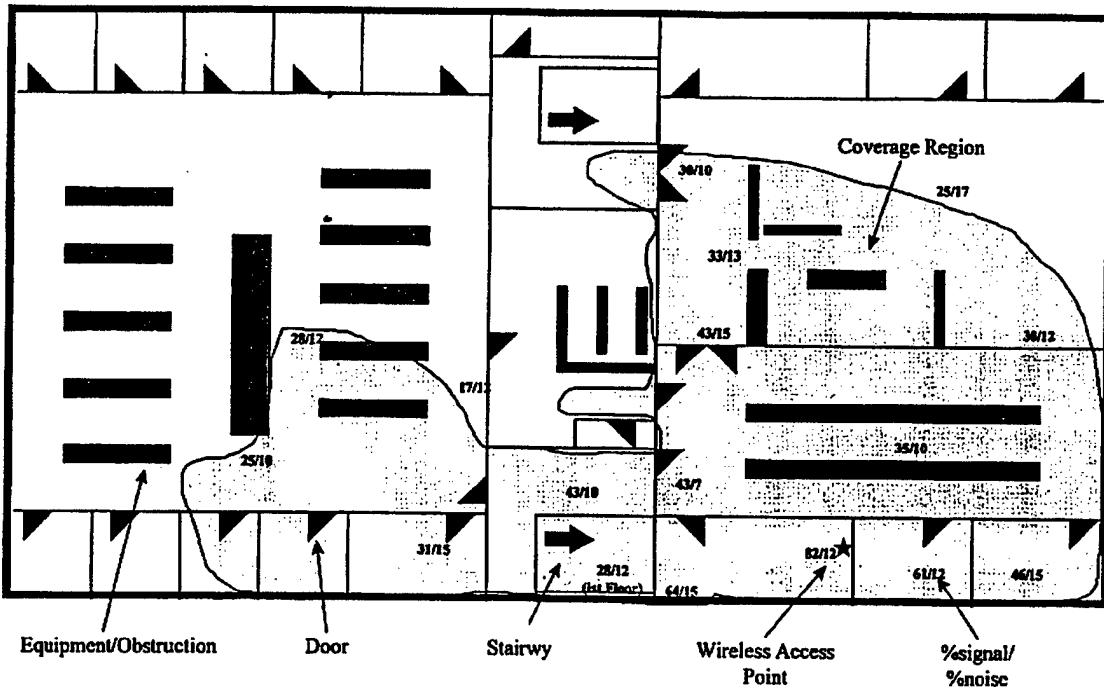

Figure 15. SNR Measurements for the Second Floor of Bullard Hall (From Ref. [8])

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To present an additional comparison of the relative signal levels predicted by the simulation and the measured signal levels, Table. 1 was created. In this table the results shown in Fig. 15 have been converted to dB and scaled so they can be compared with the relative signal levels predicted by the simulation wich are presented in Fig.18.

Physical measurements (SNR), Fig 15	Physical measurements (dB), Fig 15	Simulation results (dB), Fig 18
82/12	-40	-40
61/12	-42.5	-44
43/10	-44	-45
35/10	-46	-50
30/10	-47	-61
17/12	-54	-63

Table 1. Comparison Between the Physical and Simulation Results.

B. THE SIMULATION PROCESS.

To validate the simulation predictions qualitatively, the model of the second floor of Bullard Hall (where previous measurements were taken) was developed, based on building blueprints. In order to use this model with PlaceBase software, electromagnetic characteristics of the walls were required and are listed in Table. 2.

Type of Wall	Relative Permeability	Relative Permittivity	Conductivity	Thickness (m)
Transparent	1	1	0	0
Window	1	7.4	0	0.05
Conductor	1	1.6	0.1	0.1
Staircase	1	4.4	0.02	0.4
Concrete	1	4	0.05	0.25
Concrete Slab	1	4	0.05	0.40
Plaster	1	2.3	0.03	0.1

Table 2.   Wall Parameters Used in the Simulation.

PlaceBase provides two working screens of input data: one screen to enter information on the location, size and composition of the walls and another screen for "slabs," which in this case are floors and ceilings, as shown in Figs. 16 and 17, respectively. This requires that the thickness of the walls, floors, and ceilings and their composition be known prior to model construction. Most of the building wall surfaces are plaster, glass windows, and concrete. The floor and ceiling are forty by forty meters concrete slabs. Most of this information was available from blue prints and from a physical inspection of the building. Different wall types are represented by the variety of colors on the Walls Editor Screen, shown in Fig. 16.

A slab editor screen was used in defining two staircases and the thickness of the slab, as shown in Fig. 17. In addition, this screen can be used to define additional floors, for floor-to-floor propagation simulations.
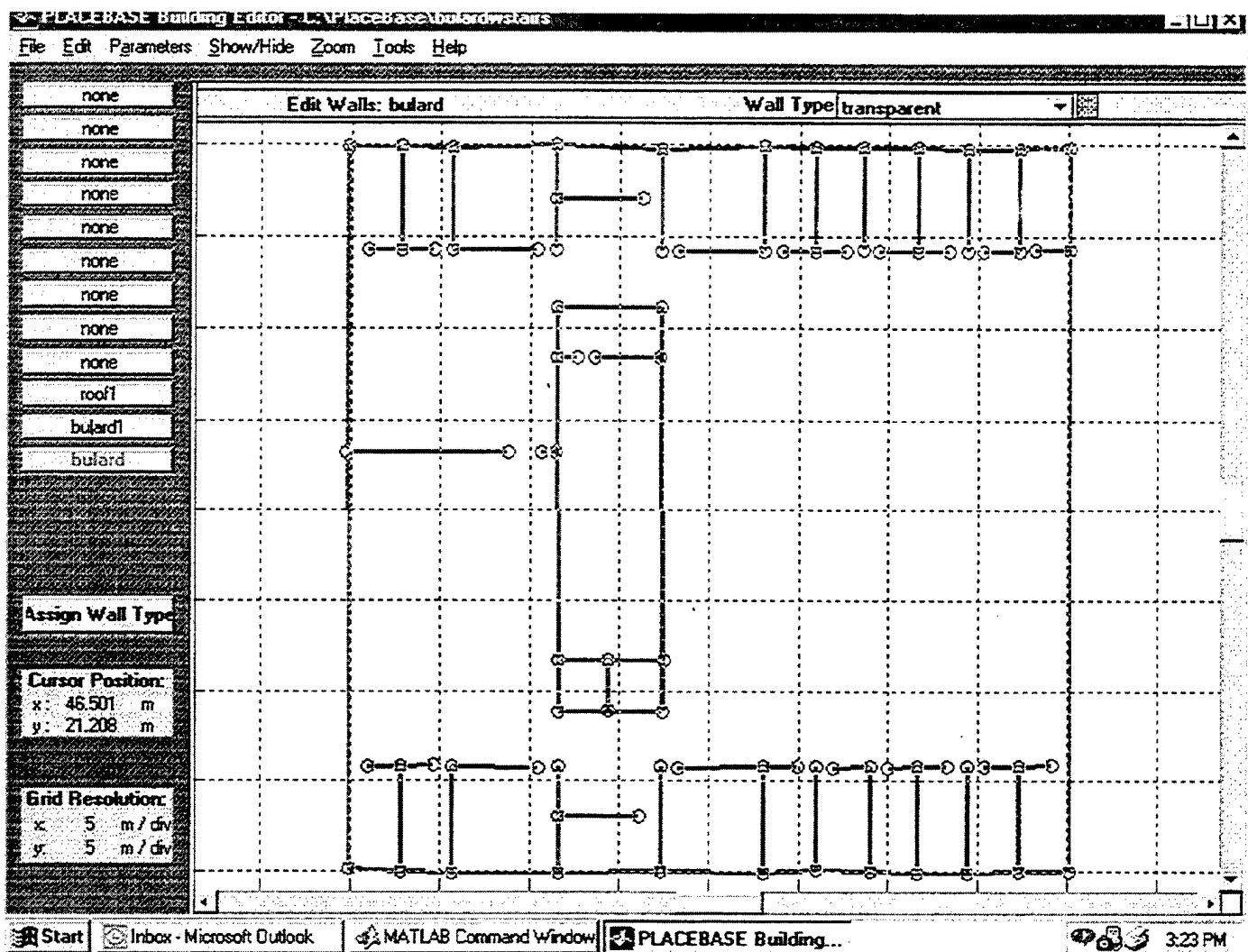
Figure 16. PlaceBase Walls Editing Window

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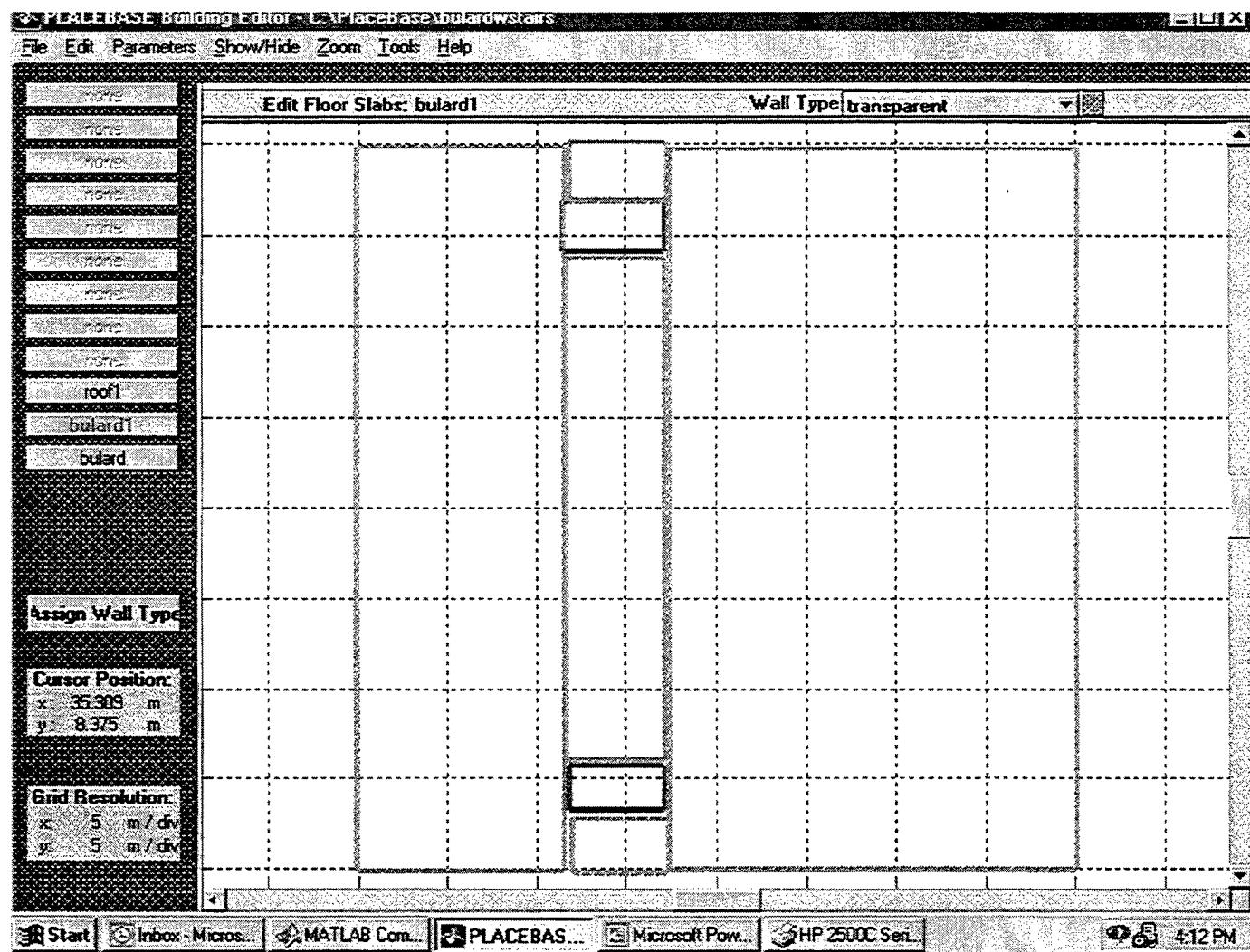
Figure 17. PlaceBase Slab Editing Window

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After completing the editing of the walls and the slabs (floors/ceilings), it is necessary to define the transmitter: type, power, frequency (2.4 GHz) IEEE 802.11b, and the source coordinates (x, y, z). These parameters were matched with those of the physical measurements and are shown in Fig. 15.

Fig. 18 shows the final simulation result for the structures of the second floor of Bullard Hall with all the walls, slabs, and transmitter parameters defined so that they best match the actual building and the conditions for the measurements. The cross (+) marks the transmitter access point location. The location and height of the AP are the same as those used for the measurements. The relative signal strength (in dB) at a height of 1.5 meters above the floor is shown in the color coverage map, with red for the highest signal strength, which is close to the transmitter.

Project: bulardwstairs   Floorname: bulard1
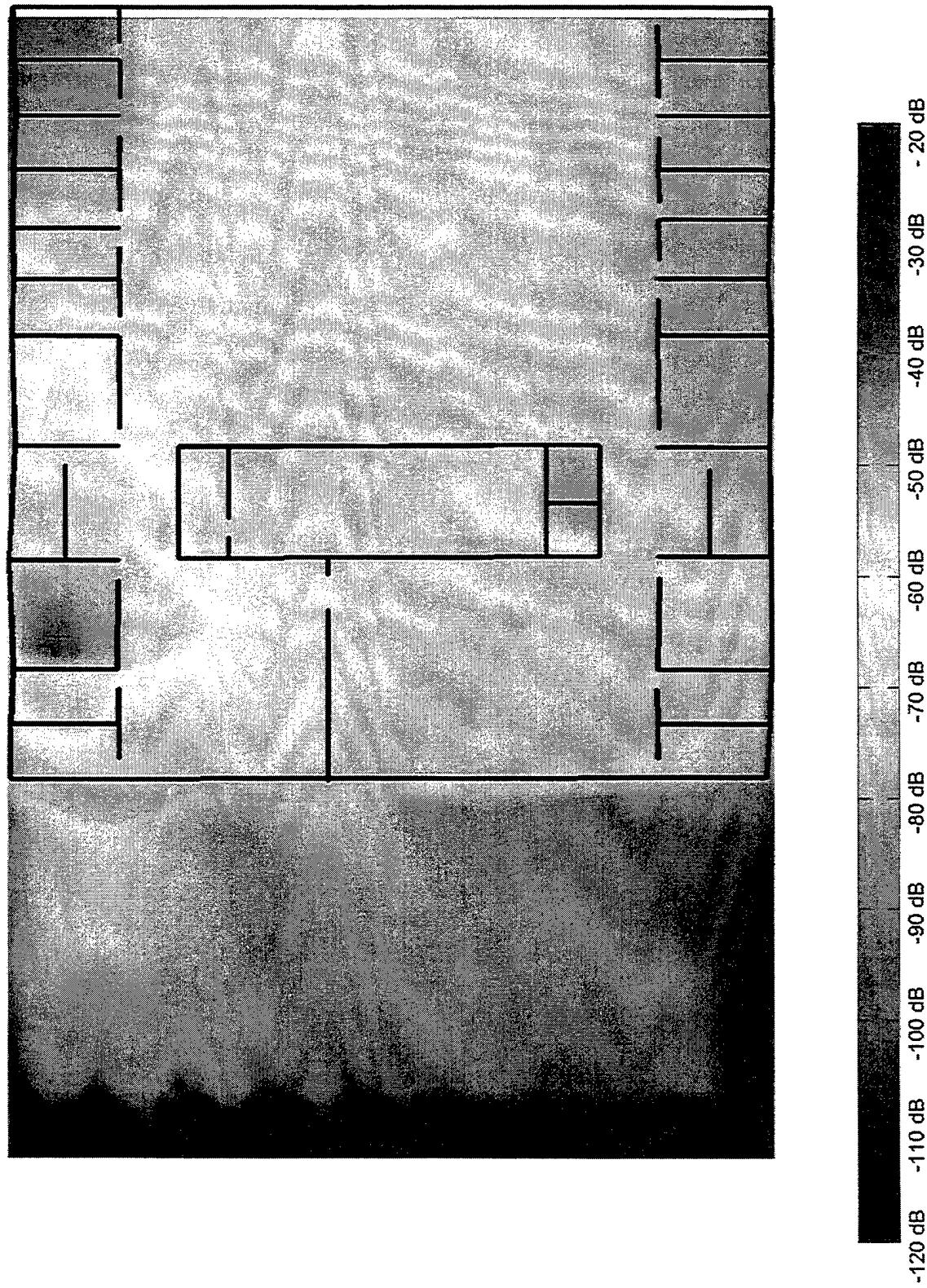
Figure 18. Second Floor Relative Signal Strength (Coverage) Map

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Tabulated measured data for coordinates and the signal strength is not available, thus only a qualitative comparison between calculations and measurements can be made. This can be done by comparing Fig. 15 and Fig. 18. Please note that the floor plans in the two figures are "reversed." (Rotating either figure by 90 degrees aligns the simulated floor plan with the measured one.) A good agreement (the overlap of the gray area from the measurements plot and the orange/yellow from the simulation) is observed from the visual comparison of Figs. 15 and 18. One problem with PlaceBase is the complexity of including furniture in the simulation model. The measured floor signal strength includes the effects of furniture, but the simulated model does not. This fact, in addition to the possible inaccuracies in the model definition (exact thickness and electrical parameters for the walls, presence of metal meshes and pipes inside the walls, etc.) would most likely account for the differences between the simulated and measured values.

In addition to signal strength prediction for the floor which houses the transmitter, PlaceBase also includes floor-to-floor propagation prediction. In Fig. 19 and Fig. 20, the signal strength is shown for the following two cases:

- When we do not have a significant opening between the two floors, and

- When the model includes a staircase between the two floors.

There is a significant propagation from the second floor to the first floor, even without the staircase. This is due to floor-to-floor propagation through slabs/walls, windows, vent

ducts and elevator spaces, etc. The signal strength on the first floor increases, as expected,

with the staircase included in the model.

Project: BULARD9   Floorname: bulard
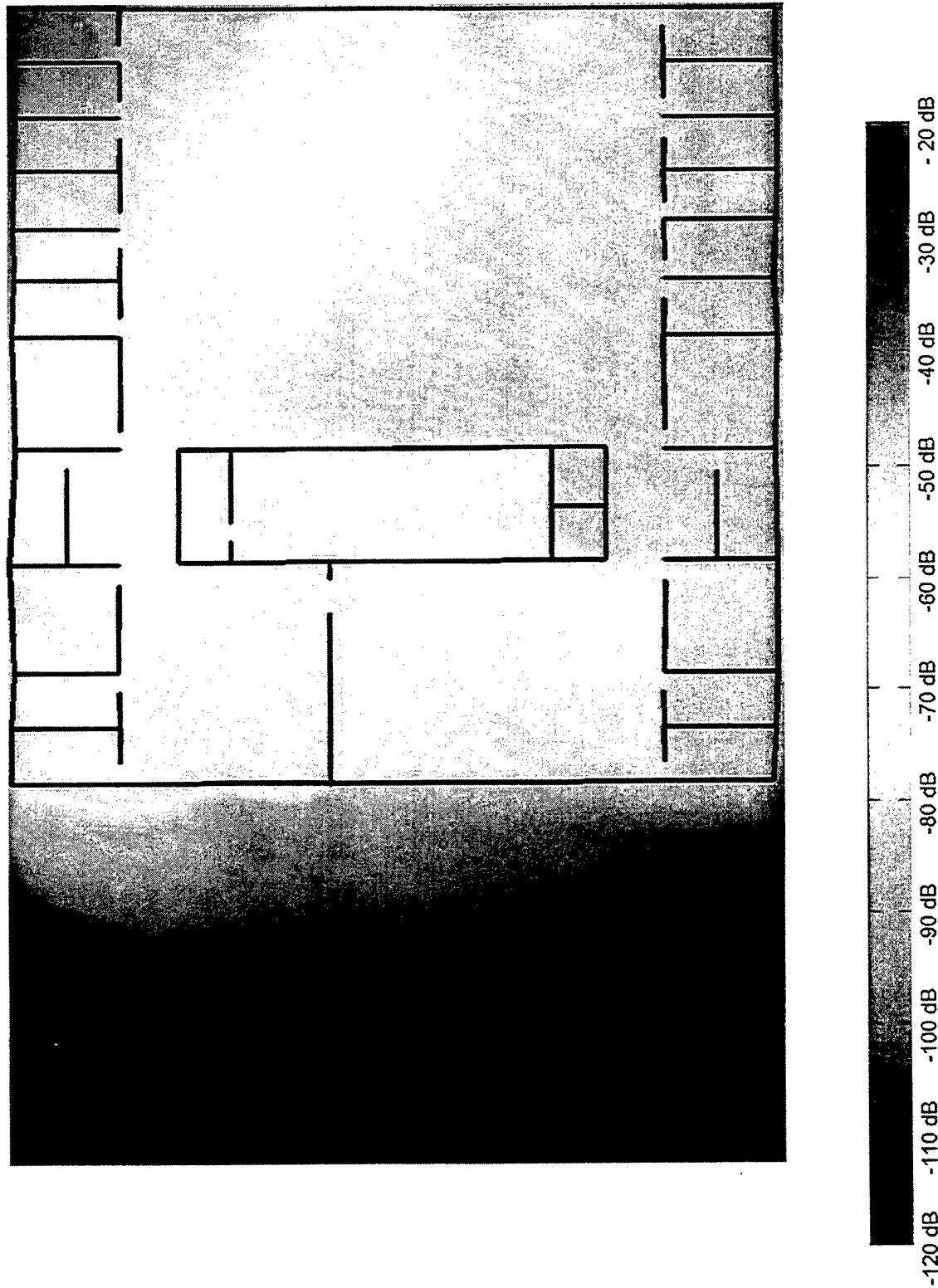
Figure 19. Signal Strength for First Floor without Staircase between the Floors

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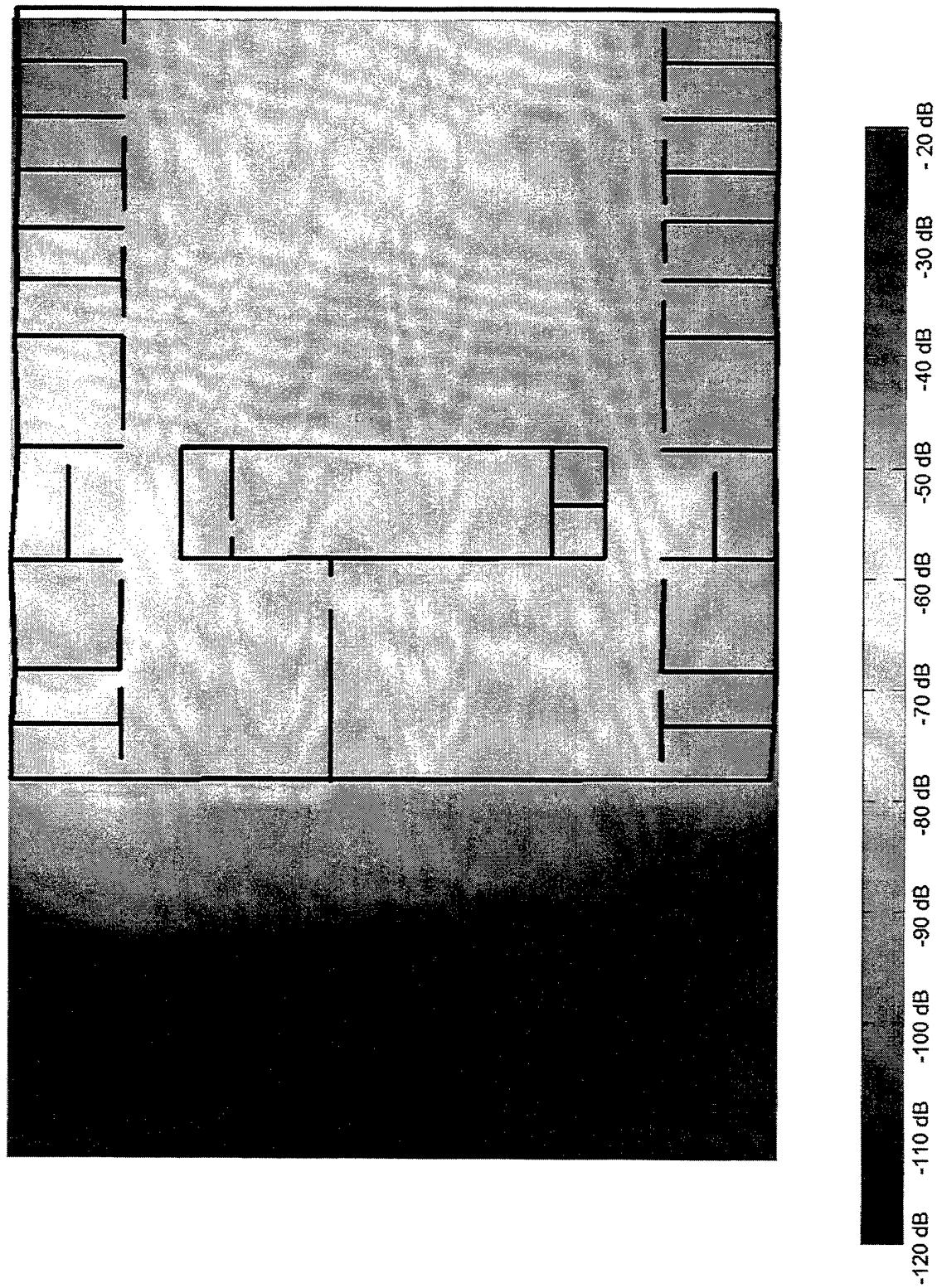
Figure 20. Signal Strength for the First Floor with Staircase between Floors

From Chapter II, recall the objective in setting up a WLAN is to enable the clients to move throughout the WLAN area without losing network contact. This can be achieved by having more than one access point. As shown in Figs. 21 and 22, adding one more access point increases the uniformity of the signal strength and thus the reliability of the WLAN connection for a mobile user.

As an alternative to using multiple access points, the transmitted power may be split among several antennas, separated in space so that they provide improved reliability of the WLAN network connection [11], [14]. Another option is to implement a "distributed" antenna in the form of a radiating or "leaky" coaxial cable, where the outer conductor is "slotted" to allow radiation to escape along the cable length. These antenna options however negate the advantage of easy access point relocation.
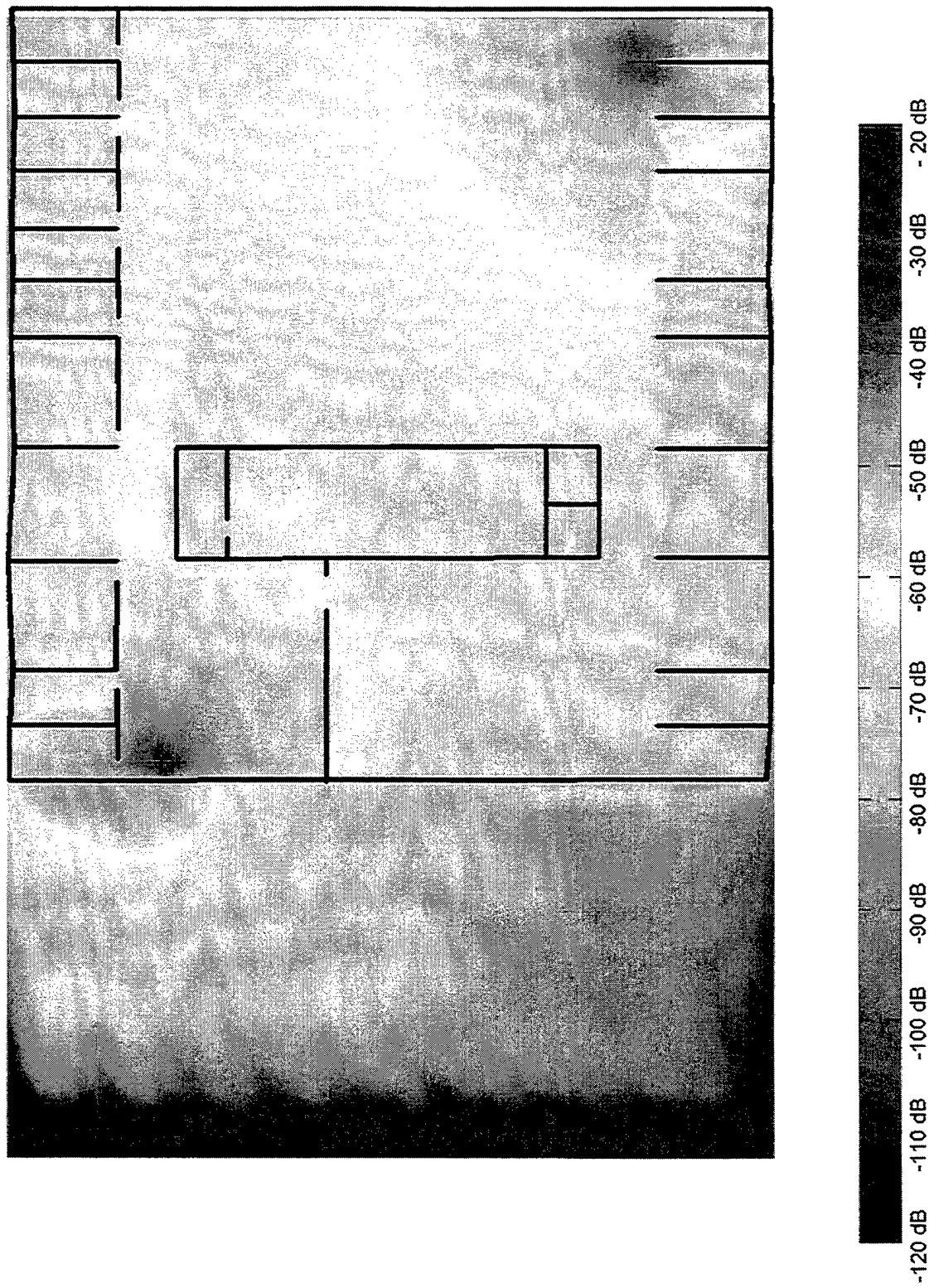
Figure 21. Signal Strength for the Second Floor with Two Access Points
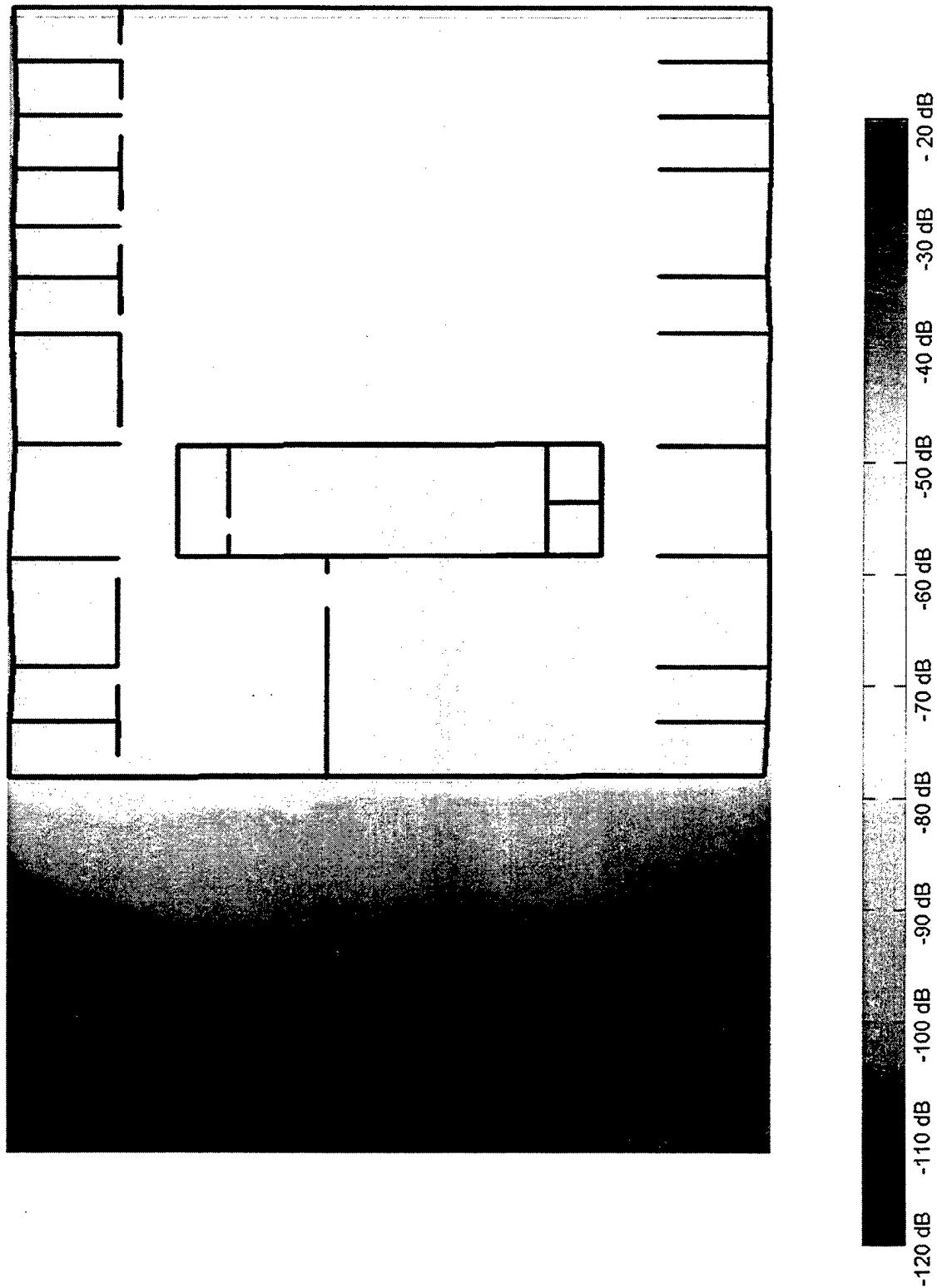
Figure 22. Signal Strength for the First Floor with two Access Points in the Upper Floor

V. CONCLUSIONS AND RECOMENDATIONS

A.   CONCLUSIONS

- By comparing the coverage area displayed in Figures 15 and 18, we are able to see the similarity in the form and the distance of the signal coverage area. In addition and to confirm the results obtained with the simulation the SNR results displayed in Fig. 15 were compared to the ones obtained in the simulation, Fig 18, this is presented in Table 1. The results from the simulation have some differences from the physical results, because the model build for the simulation did not include the furniture and other type of obstacles.

- PlaceBase can produce a signal propagation coverage map. An accurate measurement is complicated, however, because during the building of the model, the furniture and other obstacles are very difficult to include. This is an important fact to consider when analyzing PlaceBase predictions inside ships or submarines where the enclosed spaces are crowded with many objects, which can scatter electromagnetic waves.

- The average price for typical WLAN test software is $10,000. This cost is too high for use on a single installation, but for a Navy project involving the installation of multiple WLAN's, it could be both useful and cost-effective, especially if the vessel is not yet in the construction phase where physical measurements can be made.

- During the time frame of his thesis work, an explosion in the market of indoor wireless equipment has occurred. This is due to the mobility advantage that this technology offers. Different working groups, such as Bluetooth, IEEE 802.11b (high data rate), will be competing for the home and office WLAN market. This will reduce the cost of simulation software, the implementation of the equipment and the testing of these networks.

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B. RECOMMENDATIONS

- Due to the growing demand of WLAN's, software for predicting signal propagation is becoming more accurate and user-friendly. Features like three-dimensional displays, and the capability to include furniture and fine geometrical details are becoming available. The software recommended here for further investigation is the SitePlanner (Wireless Valley Communications) software addressed in Chapter III, Ref. [6].

- The Navy can reduce costs by correctly and efficiently planning the distribution of the access points, through the use of simulation and physical measurements during the initial stages of planning.

- This thesis compared physical signal measurements with simulation, from a sample of available and affordable software. Software that provides additional information is needed. Examples of such factors include simulation with the receivers moving around the enclosed space, an increased number of obstacles or people inside the space, channel interference, throughput, etc.

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